The Foundations of Science

UNIT 1

Topics to be presented in this unit include:

- The Foundations of Technology
- The Foundations of Science
- Scientific Observation and Measurement
- The Properties of Matter
- The Properties of Energy

OVERVIEW

From the beginnings of humankind, ancient people were at one with their world. Their understanding of the processes of nature were vital for their own survival. It was only a natural development for early humans to want to learn about the world in which they lived. Other creatures who shared the Earth with early humans used their own special adaptations to survive. Humans, on the other hand, used the power of thought to help them survive in the often harsh conditions that exist in nature. From these early beginnings, humans were learning about the environment in which they lived, and experimenting with new ways to improve their situation. This was certainly the beginning of what we know today as science and technology. Gathering information about the natural world, and then putting that knowledge to use in a practical form, has been a human trait for tens of thousands of years. This has resulted in a lasting relationship between science and technology, which continues to advance the human condition.

Our picture of the Universe has been assembled bit by bit from many separate discoveries—discoveries made by scientists from many parts of the world, at many times in the past, and in many disciplines. How those discoveries led to our current knowledge is the subject of this chapter. For convenience in our discussion, we will divide the history of Western astronomy into four main periods that can be characterized as follows:

Prehistoric (before 500 B.C.):* In the prehistoric era, people observed the daily and seasonal motions of the Sun, Moon, and stars and learned to use their cyclic motions for keeping time and determining direction.

Classical (500 B.C.–A.D. 1400): In the classical period, scientist-philosophers began to make measurements of the heavens and, with their knowledge of geometry, constructed idealized models that could account for the motion of heavenly bodies.

Renaissance (1400–1650): In the Renaissance period, those geometrical models were reassessed and found wanting. Astronomers therefore devised new models that took into account a much greater body of data based on observational records accumulated over centuries. Astronomers also benefited from a technological advance that allowed them to observe even more—the telescope.

Modern (1650 to the present): Finally, in the modern period, scientists began the search for the physical laws (such as the law of gravity) that underlie the observed movements in the heavens. Other important contributions to our understanding of the Universe came from technological advances (for example, in optics, electronics, and computers) and better mathematical techniques (such as calculus). Such factors continue to be important today.

1.1 PREHISTORIC ASTRONOMY

We do not know when people of antiquity first began studying the heavens, but it was certainly many thousands of years ago. Astronomical observations are part of virtually every culture and include the obvious events that anyone who watches the sky can see without the need of any equipment, such as the rising of the Sun in the eastern sky and its setting toward the west; the changing appearance of the Moon at different times of the month from new moon to crescent to full and back again; and eclipses. Other discoveries, such as the one that recognizes the planets as a class of heavenly bodies different from the stars, require more careful observation but were also probably made by prehistoric people.

FIGURE 1.1
Stonehenge, a stone monument built by the ancient Britons on Salisbury Plain, England. Its orientation marks the seasonal rising and setting points of the Sun.
(Courtesy of Tony Stone/Rob Talbot.)

For many prehistoric people, observations of the heavens had more than just curiosity value. Because so many astronomical phenomena are cyclic—that is, they repeat day after day and year after year—they can serve as time keepers. For example, when is it safe to set out on a sea voyage? When is it time to harvest crops? When will an eclipse occur? Moreover, the cyclic behavior of the heavens implies that many events seen in the sky are predictable. Thus, some of the impetus for studying the heavens probably came from the desire to foretell future events there, and it may have motivated early cultures to build monumental stone structures such as Stonehenge (fig. 1.1).

Ironically, many of the astronomical phenomena well known to ancient people are not nearly so familiar to people living today because the smog and bright lights of cities make it hard to see the sky and its rhythms. Perhaps more important, we no longer rely upon direct astronomical observations to tell us what season it is, when to plant, and so on. Therefore, if we are to appreciate the growth of astronomical ideas, we need to first understand what our distant ancestors knew and what we ourselves can learn by watching the sky over the course of a year.

*A few written records of astronomical observations made by astronomers in ancient China, India, Korea, and Japan predate 500 B.C.

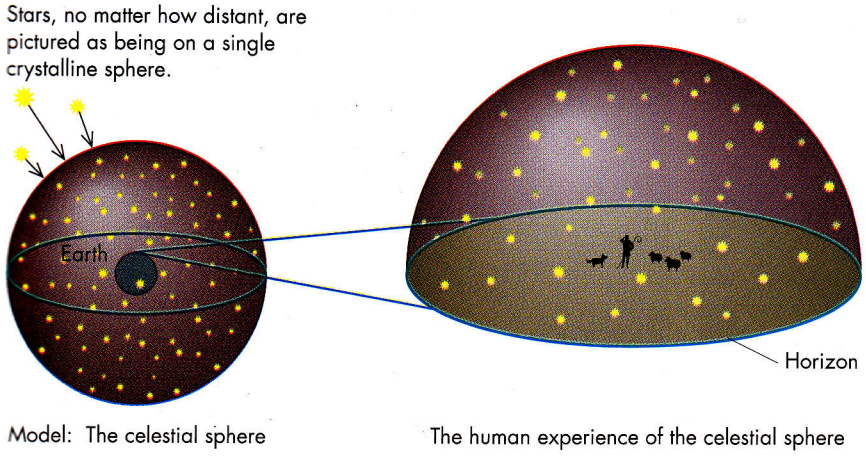

FIGURE 1.2
The sphere of the sky surrounds the Earth and is called the "celestial sphere."

One of nature's spectacles is the night sky seen from a clear, dark location with the stars scattered across the vault of the heavens. The night sky is a particularly appropriate place to begin our study of the history of astronomy because its array of stars has changed very little over the last several thousand years. The night sky affords us a direct link with what our remote ancestors viewed as they tried to understand the nature of the heavens. Thus, our first goal is to familiarize ourselves with some general aspects of the sky at night.

In the following discussion, you might want to imagine yourself as a shepherd in the Middle East, a hunter-gatherer on the African plains, a trader sailing along the coast of the Mediterranean, or even a ship's navigator in the early twentieth century. Whichever role you choose to assume, try to get out and actually look at the sky.

The Celestial Sphere

The thousands of stars visible on a clear night are at vastly different distances from us. For example, the nearest star is about 4 light-years away, but others are hundreds of times more distant. Such huge distances prevent us from getting any sense of their true three-dimensional arrangement in space. For purposes of naked-eye observations, we can therefore treat all stars as if they are at the same distance from the Earth, imagining that they lie on the inside of a gigantic dome that stretches overhead. Astronomers envisage this dome as part of the **celestial sphere** and picture it completely surrounding the Earth, with the Earth at its center, as depicted in figure 1.2.*

The celestial sphere has no physical reality, but it serves as a **model** of the heavens—an easy way to visualize the arrangement and motions of celestial bodies. We use the term *model* to mean a representation of some aspect of the Universe. That is, the celestial sphere represents a way of thinking about or viewing the location and motions of stars and planets. The celestial sphere is the first of many models we will encounter that humans have used to describe the known Universe. In later chapters, we will use models to enhance our understanding whenever the size or other properties of what we study fall outside the range of our everyday experience. Thus, we will speak of models of atoms, models of stars, and models of the Universe itself.

Constellations

As human beings, we seek order in what we look at. Thus, when ancient people looked at the night sky, they noticed that the stars form fixed patterns on the celestial sphere, what we today call **constellations.** Sometimes these constellations resemble animals if

*In figure 1.2 and many others throughout the book, distances and sizes of astronomical bodies are exaggerated for clarity.

FIGURE 1.3

The two constellations Leo, (A), and Cygnus, (B), with figures sketched in to help you visualize the animals they represent.

(Photo [A] from Roger Ressmeyer, digitally enhanced by Jon Alpert. Photo [B] courtesy of Eugene Lauria.)

we use a little imagination. For example, the pattern of stars in Leo looks a little like a lion, whereas that of Cygnus looks like a swan in flight, as depicted in figure 1.3. As you will realize when you learn to identify the constellations, many have shapes that bear little resemblance to their namesakes. Also, keep in mind that stars in a constellation generally have no physical relation to one another. They simply happen to be in more or less the same direction in the sky.

All stars move, but as seen from Earth, their positions change very slowly, taking tens of thousands of years to make any noticeable shift. Thus, we see today virtually the same pattern of stars that was seen by ancient peoples. A shepherd who lived 5000 years ago in the Middle East would have no trouble recognizing the star patterns of the night sky we see and might even call them by the same names.

We do not know how the constellation names were chosen, but most of them date back thousands of years. In fact, we don't know when the names were first given to the constellations or why, although there is some evidence they served as mnemonic devices for keeping track of the seasons and for navigating. For example, the beginning of the stormy winter months, when sailing was dangerous and ships were often wrecked, was foretold by the Sun's appearance in the constellations Pisces and Aquarius, the water constellations. Likewise, the harvest time was indicated by the Sun's appearance in Virgo, a constellation often depicted as the goddess Proserpine, holding a sheaf of grain.